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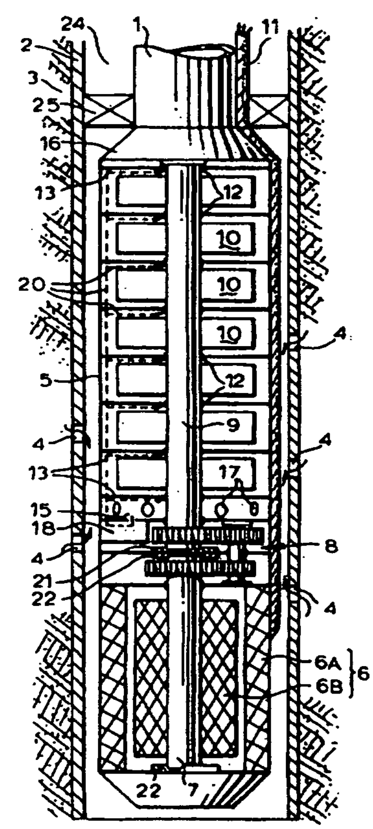
(57) Abstract

Fluid flow in a natural gas well is stimulated by means of a downhole multi-stage rotary compressor (10) which is driven by an electric motor (6). Preferably the compressor shaft (9) is equipped with gas journal bearings (12), the motor is a brushless permanent magnet motor which is capable of operating at a speed above 5000 RPM and which directly drives the compressor shaft (9), and the production tubing (1) is thermally insulated by evacuated the surrounding annular space.



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DOWNHOLE FLOW STIMULATION IN A NATURAL GAS WELL

The invention relates to a method and apparatus for downhole flow stimulation in a natural gas well.

When natural gas is produced from an ageing gas field in which the formation pressure is declining the velocity of the produced gas will decline as well. This often leads to a situation where the velocity of the gas becomes insufficient to move liquids existing in or condensing from the produced gas upwardly through the production tubing towards the surface.

At that stage the problem of liquid loading occurs. At the onset of liquid loading the gas production rate typically begins to drop at a fairly rapid rate which is a manifestation of the weight of the condensed water and other condensates that accumulate in the production tubing. After the liquid loading has continued for some time the gradually increasing weight of the liquid column in the production tubing may eventually balance the formation pressure whereupon fluid production is halted and the well dies.

US patent specification No. 3,887,008 discloses that the upward fluid velocity in a conventionally sized production tubing should be maintained at about 1.5-3 m/s in order to propel liquid droplets through the tubing against the effect of gravity. This prior art reference further discloses that the fluid velocity in a production tubing may be increased by recirculating dried gas into the well and using the recirculated gas to drive a downhole jet pump. A disadvantage of this known technique is that a jet pump has a low efficiency so that a relatively large proportion of the produced gas has to be recirculated.

US patent specification No. 5,105,889 discloses another jet pump design whereby condensed liquids may be lifted from a gas well. US patent specification No. 5,211,242 discloses that a downhole liquid collection chamber may be used when liquid loading occurs in a gas well and that the liquid may be intermittently lifted out of the well by intermittently injecting high pressure gas into the chamber via a gas injection tubing which is parallel to the production tubing. This prior art reference further discloses that the production tubing may be heated to minimize condensation and liquid fallout.

Disadvantages of the techniques disclosed in this prior art reference are that heating of the production tubing is costly and that the intermittent injection of high pressure gas to remove liquid from the collection chamber becomes costly if it has to be done on a frequent basis if the gas has a high liquid content.

It is an object of the present invention to provide a method and apparatus for downhole flow stimulation in a gas well which enable a continuous reduction of liquid loading without the requirement of intermittent or continuous re-injection of produced gas and which can be used efficiently even if the produced gas has a high liquid content and the formation pressure is low.

The apparatus according to the invention comprises a multi-stage rotary compressor which is driven by an electric motor and which is suitable for use at a downhole location in a gas well.

Preferably the apparatus comprises a compressor having a shaft equipped with gas bearings. It is preferred that this compressor is provided with a separate gas compression unit for supplying a fraction of the produced gas to the gas bearings for the creation of

a gas film between a stator and a rotor part of each bearing when the compressor is in use.

It is furthermore preferred that the gas compressor is driven by a brushless electric motor with a rotor comprising rotating permanent magnets that produce a first magnetic field and a stator comprising an armature winding which is connected to a source of electrical current to produce a second magnetic field, said first and second magnetic field being capable of interacting to create an electromagnetic torque that induces the rotor to rotate relative to the stator.

Motors of this type are known for use in various applications and disclosed, for example, in US patent specifications Nos. 4,125,792; 4,276,490; 4,443,906 and 5,428,522 and in European patent specification No. 533,359.

The known motors, however, are not designed for downhole use in hydrocarbon fluid production operations and a surprising benefit of these motors for use downhole is that they can be designed as a small diameter drive unit which operates at much higher rotational speeds than other electric motors so that the motor shaft can be connected directly to the compressor shaft and the presence of a gear box between these shafts may be eliminated.

It is observed that European patent specification No. 480501 discloses the use of an electrically driven downhole pump with a helical screw blade in a gas well, but that this known pump is believed unsuitable for pumping of large volumes of gas at such high velocity through the production tubing that the problem of liquid loading would be effectively reduced.

In accordance with one aspect of the method according to the invention this object is accomplished by boosting the gas velocity in a production tubing within the well

by means of a multistage rotary compressor driven by an electric motor which is mounted at a downhole location within the well. The compressor will usually be installed at such a depth within the well that condensation is insignificant at the relevant depth.

Preferably, the compressor has a shaft which is equipped with gas bearings and when the compressor is in use a fraction of the produced gas is compressed by a separate gas compression unit and supplied to the gas bearings in order to create a gas film between stator and rotor parts of these gas bearings.

It is also preferred that the gas compressor is driven by an electric motor which is controlled by power control means which limit power exerted by the motor shaft to the compressor such that the discharge temperature of the gas compressed by the compressor is maintained below 250 °C.

It is furthermore preferred that the production tubing is provided along part of its length with a thermal insulation and that this thermal insulation is provided by filling an annular space surrounding the production tubing along at least part of its length with a gaseous fluid and by at least partly evacuating said space.

In accordance with another aspect of the method according to the invention reduction in velocity of the fluid mixture in a gas well is counteracted by the step of thermally insulating the production tubing preferably by filling an annular space surrounding the tubing along at least part of its length with a gaseous fluid and by at least partly evacuating said space.

Since the reservoir temperature of subsurface gas bearing formations is about 100 °C and the temperature of formation layers surrounding the gas well will gradually decline towards the atmospheric temperature at the

surface, the produced gas will gradually cool off. By insulating the production tubing the reduction of the temperature of the produced fluid is reduced thereby reducing the velocity decrease resulting from thermal compaction and also delaying the onset of liquid loading.

These and other features, objects and advantages of the method and apparatus according to the invention will become apparent from the accompanying claims, abstract and drawing which shows a schematical, partially longitudinal sectional view of the apparatus according to the invention.

Referring now to the drawing, there is shown a pumping apparatus according to the invention which is suspended at the lower end of a production tubing 1 within a gas production well. A casing or production liner 2 is arranged at the inner circumference of the wellbore to prevent caving in of the surrounding formation 3. The casing or production liner 2 contains perforations 4 to permit inflow of fluids from the gas bearing formation 3 into the wellbore.

The apparatus according to the invention comprises a cylindrical housing 5, an electrical motor 6 having a stator part 6A and a rotor part 6B which is mounted on a motor shaft 7, a gear box 8 for transmitting power from the motor shaft 7 to a compressor shaft 9, and a multi-stage rotary compressor 10 which is mounted on the compressor shaft 9.

Electrical power is supplied to the motor 6 via an umbilical 11. The motor compartment and gear box compartment of the housing 5 are filled with oil and the umbilical 11 may comprise oil supply conduits for the supply of lubricant during operation of the apparatus.

Due to the limited width of the wellbore the multi-stage rotary compressor 10 has an elongate shape and contains a large amount of stages. Consequently, the

compressor shaft 9 is also so long that it has to be supported by a series of journal bearings 12 which are mounted between at least some of the compressor stages.

These journal bearings 12 are supported by support disks 13 which are perforated (not shown) to permit the produced gas to flow from an inlet section 15 of the compressor via the first and subsequent stages of the compressor 10 towards the outlet section 16.

The housing 5 contains a series of openings 17 at the inlet section 15 of the compressor 10 to permit inflow of gas from the wellbore into the housing 5.

In view of the significant amount of journal bearings 12 and the elevated temperature and pressure of the produced gas it would be impractical to lubricate the journal bearings 12 by a liquid lubricant, in particular because the large amount of seals required to provide a fluid barrier at each side of the journal bearings 12 would generate significant friction which would even further increase the lubricant temperature and which would also require a significant extra power requirement for the motor.

It is therefore beneficial to lubricate the journal bearings 12 with the produced gas. The gas is supplied to the journal bearings via a small compressor unit 18 which is mounted in a recess within the gear box section 8 and a branched high pressure gas supply line 20 which is shown in dotted lines.

The gas compressor unit 18 may be driven by the electric motor 6. Alternatively the unit 18 may be driven by a separate electric motor which supplies the gas to the journal bearings 12 at a constant pressure even during start-up or run-down of the multi-stage rotary compressor.

The journal bearings 12 may be gas bearings of the pivoted pad or herringbone groove type. Bearings of this

type are known per se, and are described, for example, in the Mechanical Engineers Handbook, Edition 1986, page 488-567, published by John Wiley & Sons, and are therefore not described in detail herein.

In the configuration shown in Fig. 1 the thrust bearing 21 of the compressor shaft 9 is mounted at the bottom of the gear box section 8 and is therefore a conventional oil lubricated trust bearing. However, if desired, the thrust bearing could also be mounted within the gas inlet 15 of the compressor 10, in which case the thrust bearing could be a gas bearing as well.

The bearings 22 of the electric motor 6 are conventional oil lubricated bearings.

It is preferred to use in the apparatus according to the invention gas bearings for the journal bearings 12 of the pump shaft 9 since, as described above, this obviates the need for a large amount of shaft seals, and moreover since gas bearings are able to run at much higher temperatures than oil lubricated bearings.

This is a significant advantage for a downhole gas compressor since it would be difficult and expensive to cool the apparatus. However, since it is still required to use liquid lubricants in the gear box 8 and motor 6 it is preferred to equip the electric motor 6 with power control means which limit the power exerted to the pump shaft 9 such that the discharge temperature of the compressed gas at the outlet 16 is maintained below 250 °C.

The temperature increase of the compressed gas is beneficial for the reduction of liquid loading in the production tubing 1. However, the production tubing may be several kilometres long such that a significant cooling of the gas does occur.

In order to reduce the cooling-off of the produced gas within the production tubing 1 it is preferred to

insulate the tubing 1 by creating a low gas pressure in the annular space 24 that extends between the production tubing 1 and the well casing 2 from a packer 25 towards the wellhead (not shown).

Preferably the annular space 24 is first filled with an inert gas, such as nitrogen, and then evacuated. In this way the annular space 24 acts as an efficient thermal insulator which reduces the cooling of the produced gas and the condensation of aqueous liquids that may be present in the gas to a significant extent.

It will be understood that instead of or in addition to the presence of a vacuum insulation in the annular space 24 the production tubing 1 may also be insulated by other insulation means, such as a conventional foam insulation sleeve.

It is preferred that the electric motor 6 is a brushless motor having a rotor part 6B comprising rotatable permanent magnets that produce a first magnetic field and having the stator part 6A comprising an armature winding (not shown) which is connected to a source of electrical current to produce a second magnetic field, which first and second magnetic fields are capable of interacting to create an electromagnetic field that rotates in use the rotor part 6B relative to the stator part of the motor 6.

An electric motor 6 of the above described type is able to deliver optimum torque at rotor speeds well over 5000 revolutions per minute, which will make the presence of the gear box 8 obsolete.

The absence of a gear box 8 and the use of gas bearings as journal bearings 12 is attractive since it creates a compact motor and compressor assembly with a minimum of oil filled compartments which would require regular replacement of oil and maintenance and inspection of wear prone components such as seals and gaskets.

CLAIMS

1. An apparatus for enhancing fluid flow in a gas well, the apparatus comprising a multi-stage rotary compressor which is driven by an electric motor and which is adapted for use at a downhole location in a gas well.

2. The apparatus of claim 1, wherein the compressor has a shaft which is equipped with gas bearings and the compressor is provided with a separate gas compression unit for supplying a fraction of the product gas to the gas bearings for the creation of a gas film between a stator and a rotor part of each bearing when the compressor is in use.

3. The apparatus of claim 1 or 2, wherein the electric motor is a brushless motor with a rotor comprising permanent magnets that produce a first magnetic field and a stator comprising an armature winding which is connectable to a source of electrical current to produce a second magnetic field, said first and second magnetic field being capable of interacting to create an electromagnetic torque that induces the rotor to rotate relative to the stator.

4. The apparatus of claim 3, wherein the electric motor has a shaft which is directly connected to the shaft of the compressor.

5. The apparatus of claim 3 or 4, wherein the electric motor is capable to operate at a speed of more than 5000 revolutions per minute.

6. A method for enhancing fluid flow in a gas well comprising the step of increasing the gas velocity in a production tubing within the well by means of a multi-stage rotary compressor driven by an electric motor

according to any preceding claim which is mounted at a downhole location within the well.

7. The method of claim 6, wherein the gas velocity is increased to such a level that throughout the length of the production tubing the gas velocity is maintained above the level at which liquid loading would occur.

8. The method of claim 6 or 7, wherein the gas compressor is driven by an electric motor which is controlled by power control means which limit power exerted by the motor shaft to the compressor such that the discharge temperature of the gas compressed by the compressor is maintained below 250 °C.

9. The method of claim 6, 7 or 8, wherein the production tubing is provided along at least part of its length with a thermal insulation.

10. The method of claim 9, wherein the thermal insulation is provided by filling an annular space surrounding the production tubing along at least part of its length with a gaseous fluid and by at least partly evacuating said space.

11. A method for enhancing fluid flow in a gas well comprising the step of thermally insulating a production tubing within the well through which the gas is produced along at least part of its length.

12. The method of claim 11, wherein the production tubing is thermally insulated by filling an annular space surrounding the tubing along at least part of its length with a gaseous fluid and by at least partly evacuating said space.

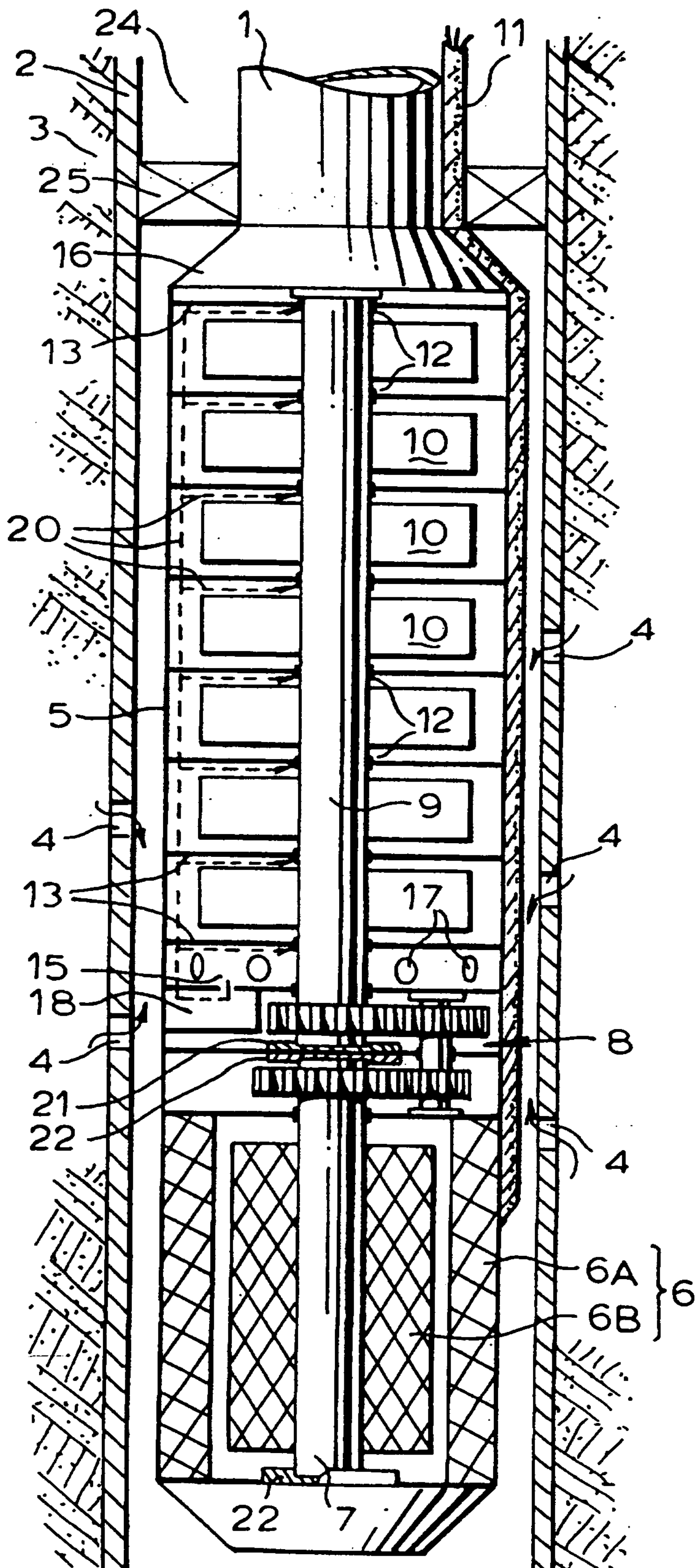
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Fig. 1